research review

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Concepts of Energy and Momentum in General Relativity

DR. LOUIS TAMBURINO, General Physics Research Laboratory, ARL

The concepts of energy and momentum, so basic to physics, encounter serious difficulties in Einstein's general theory of relativity. It is necessary to discuss the idea of invariance groups in order to identify the source of these difficulties.

Loosely speaking, an invariance group is any group of transformations that leaves a given set of physical laws unchanged. For example, if the dynamical equations of some system do not depend on the location of the origin of the coordinate frame, then the invariance group is $\overline{x} = x + \epsilon$ where the parameter ϵ is the increment of translation.

Invariance properties are of fundamental importance. Firstly, they provide a useful guide or test for the derivation of new laws; and secondly, they are powerful tools for finding solutions. In particular, they lead to conservation laws. The translational invariance above leads to conservation laws of linear momentum.

There are many symmetry or invariance groups being considered in contemporary physics. For instance, the transformation from right-handed to left-handed coordinate systems is associated with conservation of parity. For our present purposes, attention is focused on continuous groups of coordinate transformations; these lead to conservation laws of energy and momentum.

Historically, the invariance properties of Newtonian physics were formalized in the Galilean transformation group, which was in harmony with the erroneous notions of "action at a distance" and absolute simultaneity. However, the electromagnetic field theory was found to be incompatible with this invariance group. This situation ultimately led to Einstein's special theory of relativity which postulated a new invariance group called the Lorentz transformations. The revolutionary success of this theory underlies modern physics.

Only the gravitational field resisted any attempt to be anchored to Lorentz invariance. In order to obtain a relativistic description of the gravitational field, Einstein proposed his general theory of relativity which contained still another and more extensive invariance group. In the general theory, the gravitational field is embodied in the geometry of a curved, 4-dimensional universe. The notion of inertial frames, basic to special relativity, is discarded, and all coordinate frames become equally suitable for a formulation of physical laws. Note that the invariance group comprises all continu-

ous curvilinear coordinate transformations, thus involving 4 arbitrary functions. This is in sharp contrast with the Galilean and Lorentz invariance groups which are characterized by 10 arbitrary parameters such as the relative velocity of inertial frames, and parameters that measure linear and rotational displacements of the coordinate system.

According to an important theorem by E. Noether, an n-parameter invariance group induces n conservation laws for n physical quantities. The Lorentz and Galilean groups have a finite number of parameters; so Noether's theorem provides a straightforward prescription for finding conserved quantities in systems that have these invariance groups. On the other hand, the invariance group of general relativity involves arbitrary functions which have an infinite number of one-parameter groups as subgroups; hence there are, in effect, an infinite number of conservation laws. This is a dilemma that has plagued physicists for years: how does one find an intrinsic subgroup that leads to natural definitions of energy and momentum?

This disturbing situation is not altogether hopeless. Various approaches have been proposed, none of which, however, are completely satisfactory or broad enough to apply to general physical systems.

One approach, related to the problem of gravitational radiation, seeks to restrict the invariance group through physically reasonable asymptotic boundary conditions. The motivation here is to find an asymptotic group that approaches the Lorentz group in regions of space where the influence of the gravitational field is negligible. Several of these asymptotically restricted groups have been investigated by H. Bondi and his coworkers, R. Sachs and P. Bergmann, in research programs supported in part by ARL.

One interesting group that evolved, the Generalized Bondi-Metzner (GBM) group, contained not only the Lorentz group but also additional transformations. Bondi and Sachs

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JACOB SEIDEN
Editor

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were able to define the total energy momentum radiated to infinity with this GBM group; however, the full implications of this result are not yet completely understood. A group with similar features has appeared in an investigation of gravitational dynamics in finite regions of space* undertaken at ARL by J. Winicour and the author of this article.

Sachs argues that, since the GMB group is so strikingly similar to the Lorentz group, perpaps this invariance may be compatible with present microphysics. ★

*presently being prepared for publication.

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LIGHT SCATTERING by AEROSOLS

LOUIS ELTERMAN

Optical Physics Laboratory, AFCRL

If a photograph taken from a satellite or a high-altitude reconnaissance aircraft on a clear day lacks the clarity and resolution of which the camera system is capable, the loss is due in part to aerosol scattering. When the energy of a laser beam is attenuated over the path between transmitter and receiver, here again aerosol scattering has played a part.

In progress at AFCRL is a novel experiment designed to measure the distributions of aerosols as a function of altitude, of time of day, and of season. The experiment involves a vertically pointing, extremely powerful, narrow-beam searchlight. Scattered light from the searchlight beam can be measured up to an altitude of 70 km from the ground. Scattering results in part from aerosols in the atmosphere. "In part" should be stressed because scattering from atmospheric molecules, or Rayleigh scattering, contributes strongly to the visibility of the beam. The searchlight is located 30 km from AFCRL's Sacramento Peak Observatory, in Sunspot, New Mexico. A telescope and recording devices at the Observatory were specially designed for the study. Measurements are made only at night and in the absence of moonlight.

The telescope at the Observatory scans up and down along the beam, recording the intensity of the light scattered from it at each point. The recorded data are reduced to determine the contributions due to scattering by atmospheric molecules and that due to aerosols. Aerosols themselves are simply nothing more than solid or liquid particles suspended in the atmosphere--dust, fog, bacteria, smoke, and so on. A particle of about one micron remains in suspension indefinitely, except at lower altitudes where drops of moisture condense on them. Some aerosol layers are believed to be permanent features of our atmosphere; other layers form, migrate and dissipate, perhaps returning ultimately back to the land-water mass or perhaps into space.

The study has been successful in identifying several layers of high aerosol concentration in the atmospheric region below 35 km. One layer occurred roughly at 10 km, at about the altitude of the local tropopause where temperature stops decreasing with altitude. The "tropopause" aerosol maximum was unexpected; further studies to investigate this anomaly are planned. A second and larger aerosol concentration was found at 19 km, where the aerosol number density tends to reach a maximum. This result was in good accord with other experiments. Above 25 km, aerosol scattering decreases rapidly, and between 35 and 70 km, almost all of the scattering is due to molecules in the atmosphere.

The program is a continuing one in order to determine daily and seasonal variations. The study will provide information not only about scattering, but also about the physical properties of the aerosols themselves. ★

earth currents and magnetic-field variations

UPPER ATMOSPHERE PHYSICS LABORATORY, AFCRL

Currents in the surface layer of the earth may account for a large part of the diurnal variations of the earth's magnetic field. Surface features of the earth--the oceans and land masses--may have some effect on other variations of the magnetic field and on phenomena in the ionosphere.

These are the implications of a study recently carried out by Dr. Hermann Poeverlein of AFCRL. The study involves well-known concepts of hydromagnetics in which changes in any one of three basic parameters--magnetic field, electric field, and velocity of a conducting medium--induce changes in each of the others. In this study, Poeverlein considered the motion of the plasma in the outer atmosphere--the magnetosphere--under the combined action of the earth's rotation and the solar plasma wind.

The earth's ionized atmosphere extends out several earth radii and includes both the upper ionosphere and the earth's radiation belts. This region is compressed by the solar plasma wind on the side of the earth facing the sun. On the night side of the earth, the magnetosphere expands outward. Because the atmosphere in this region rotates with the earth, the outer atmosphere alternately contracts and expands as it moves toward and away from the solar plasma wind. Thus, we have a moving conducting medium (the atmospheric plasma) in the presence of a magnetic field, and this results in an electric field. The electric field oscillates with a period of one cycle per day.

This electric field, originating in the outer atmosphere, reaches down to the ground. Because the surface layer of the earth is conductive, a current is induced. The current system is, of course, very weak. It varies with latitude, and is reversed at night. But it is well capable of yielding measurable diurnal magnetic-field variations on the ground. (The magnetometer used to make geomagnetic measurements cannot, of course, discriminate between the sources of a particular magnetic field--that is, it does not separate the contributions made by the earth's encircling dipole field from those induced by the surface current.)

Poeverlein has shown that the mechanism just described, a mechanism that is an indirect effect of the solar plasma wind, could account for variations in the magnetic field. But there is still another current system at the magnetospheric boundary generated by the solar plasma wind flowing around the earth's dipole magnetic field. The magnetic field accompanying this current system is too weak to be observable on the ground. Therefore, ground-recorded magnetic field variations from this source are insignificant.

The earth-surface current concept illuminates several geophysical phenomena. If the earth current system gives rise to a magnetic field, then it should be expected that this magnetic field would vary with the conducting properties of the earth's surface layer. Because oceans have a higher conductivity than land masses, one would expect some slight differences in the variable magnetic field at different locations on the earth. Certain observed peculiarities of the magnetic field may in fact indicate such geographical influences.

Another implication of the study concerns effects in the ionosphere. The electric field in the ionosphere depends also on the currents produced in the earth's surface layer. The geographical structure of the earth should consequently have some influence on this electric field and on motions of the ionospheric plasma. This may contribute to differences in ionospheric characteristics in different parts of the world. ★

compositional differences in lunar surface materials

SPACE PHYSICS LABORATORY, AFCRL

After more than one year of observations involving 24 nights on the 69-inch telescope at Lowell Observatory, Flagstaff, Arizona, scientists of the Air Force Cambridge Research Laboratories have discovered differences in mineralogical composition at different regions on the moon.

Although there is still--in spite of the excellent Ranger photographs--some uncertainty with respect to the physical properties of lunar-surface materials, there has always been a complete lack of information concerning mineralogical composition from place to place over the lunar surface. The AFCRL discovery of such compositional differences sheds light on lunar history and geology, and must be taken into account in planning lunar exploration programs. One possible implication of the discovery has to do with the origin and depth of the dust layer which is widely assumed to cover much of the lunar surface. If the dust layer were very deep and of meteoritic origin, or if it had been shed from the highlands, then one would expect a high uniformity in mineralogical composition. The differences in composition from place to place on the moon show that the surface materials are, on the contrary, primarily of local origin.

The observations were made by Drs. Graham R. Hunt and John W. Salisbury who first reported their data at the April 1965 meeting of the American Geophysical Union in Washington, D.C. Compositional differences were determined on the basis of infrared emission spectroscopy, over a spectral region of 8 to 24 microns.

One of the most significant findings revealed by Hunt and Salisbury is that Mare Cognitum, Mare Tranquilitatis and the floor of the Crater Alphonsus have a similar composition, which is entirely different from that of Mare Serenitatis. Since all of the Ranger photographs were of the areas of similar composition, the question arises as to the differences that might be found in an area like Mare Serenitatis.

One possible explanation of the compositional differences could be that the surfaces photographed by Rangers 7, 8, and 9 were all affected by secondary impacts of debris thrown out of large primary impact craters formed fortuitously in material of similar composition, while Serenitatis is unaffected in this way. Thus, it is possible that the frequency of small secondary craters is much lower on Serenitatis, as well as its being covered with material of a different composition. It appears more likely, however, that all mare surfaces are simply not composed of the same materials, which may or may not have an effect upon the physical nature of the surface. Other conclusions could be drawn, however. One outside possibility is that the apparent spectral differences are the result of a marked change in grain size, rather than of composition, of the surface material from place to place. In any case, the findings suggest that one of the important areas for further study is Mare Serenitatis.

From the spectral recordings it was not possible to learn the exact composition of the materials at different parts of the moon--only that differences exist, and that they are more granitic or basaltic than an arbitrary standard. The detailed nature of the spectrum itself is disguised by absorption of our atmosphere. It is possible to learn the mineralogical composition by infrared spectroscopy techniques only if the measurements are made from above most of the atmosphere.

For this reason, AFCRL plans to place a balloon-borne spectrometer above 99 per cent of the atmosphere--110,000 feet. The balloon measurement program, under the direction of co-worker Mr. Roger Van Tassel, has been designated Project Sky Top. Simultaneously with the balloon observations, ground-based measurements will again be made using the 69-inch Lowell Observatory telescope. These observations may provide the detailed spectral data needed to determine precise mineralogical compositions, as well as the compositional differences already discovered. ★

"short-backfire" antenna

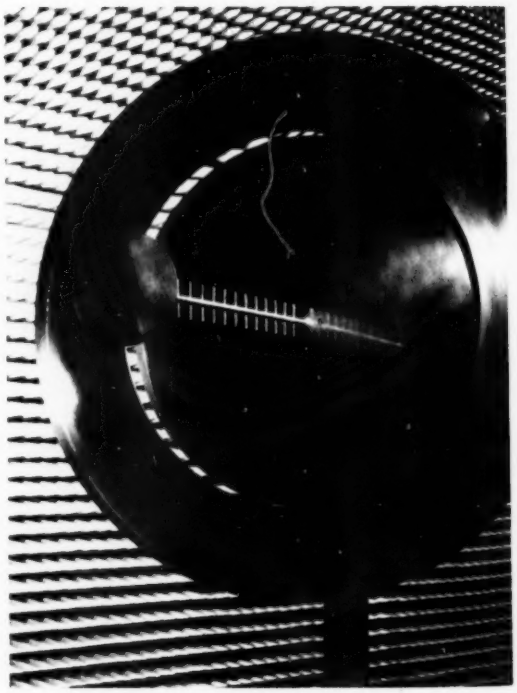
MICROWAVE PHYSICS LABORATORY
AFCRL

An antenna based on a new principle and promising major advantages in cost and size has been developed and tested by Dr. Hermann Ehrenspeck of AFCRL. This antenna has been named the "short-backfire" antenna. It has marked advantages in simplicity over conventional endfire antennas. When several are used in an array, it would have its primary application as a satellite telementry data collector. In this application, it has advantages over conventional antenna arrays and parabolas presently used.

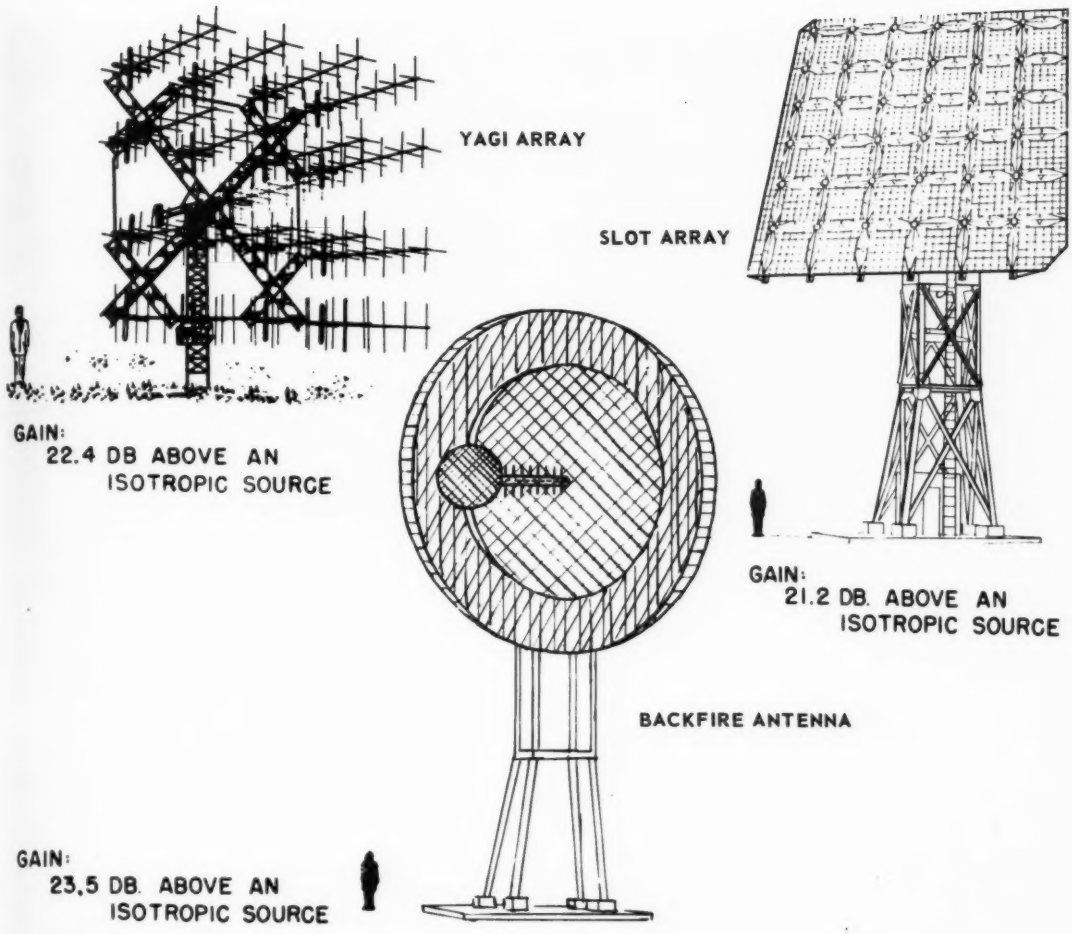
As a single element, the primary reflector of this antenna roughly resembles a pie pan. It consists of a circular flat plate 2 wave lengths in diameter, with a circular quarter-wave rim. A dipole feed is spaced a quarter-wave in front of the flat plate, and a smaller flat plate disc spaced another quarter-wave in front of the dipole. This system acts like a partially open cavity, and produces the remarkable gain of 14.5 db above isotropic. Sidelobes and the backlobe are below 20 db. The band width is comparable to that of the dipole feed itself. A Yagi comparable in gain and sidelobe level would require a length of about 5 wave lengths with at least 25 dipole elements.

In an array, consisting of several feed dipoles and discs arranged in front of a common primary reflector, the antenna achieves the same gain as a dipole or slot array for the same over-all aperture area, but with only a small fraction of a number of elements required. Thus, a 36-element slot array, producing about 21 db, can be replaced by an 8-element short-backfire array. The element feeds can be circularly (or cross) polarized, and the system as a whole lends itself to monopulse as well as pencil beam operation.

SHORT-BACKFIRE ANTENNA



BACKFIRE ANTENNA



The line drawing above shows the backfire antenna in relation to standard antennas now being used by NASA and the Air Force as part of their satellite telemetry networks.

The name, "short-backfire" antenna, derives from earlier work on another novel antenna, designated the "backfire antenna." The basic configuration of the backfire antenna is similar to that of the short-backfire antenna except that, instead of a single dipole between two reflectors, it uses several dipoles which together resemble a surface wave structure. In a report recently accepted by the Proceedings of the IEEE for publication, Dr. Ehrenspeck notes that a backfire antenna applying one single surface wave structure of 4 wave lengths has a gain of 23.5 db above an isotropic source. This gain exceeds that of an array of 16 single Yagi antennas, each 2 wave lengths long, and an array of 36 single-slot elements.

No formal theory of the backfire antenna has as yet been developed, although a qualitative approach does exist. It acts like an open cavity which, in its basic configuration and function, resembles a Fabry-Perot laser cavity, except that it is filled with air rather than an active medium. ★

COMPOSITION EQUILIBRATION IN REFRACTORY OXIDES

DR. N. M. TALLAN, H. C. GRAHAM AND J. M. WIMMER
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A knowledge of the equilibration of refractory oxides with their surrounding atmosphere becomes of increasing importance with each new demand for their use as high-temperature space componentry. Before these materials can be properly used at the extremes of oxygen partial pressures encountered in space, it is necessary to know what the effect will be on their defect structure. That is, to what extent will the material equilibrate with its new atmosphere, and how will this change affect its macroscopic properties?

It has been generally assumed that bulk equilibration of oxides with the surrounding atmospheres occurs in a relatively short time at temperatures within 200 or 300 degrees of their melting points. However, recent attempts to equilibrate alumina single crystals at 1,750°C (melting point 2,050°C) in various oxygen partial pressures have shown this assumption to be incorrect for this material.

Figures 1 and 2 give representative results for two samples after heat treatment. Treating the results as interfacial polariza-

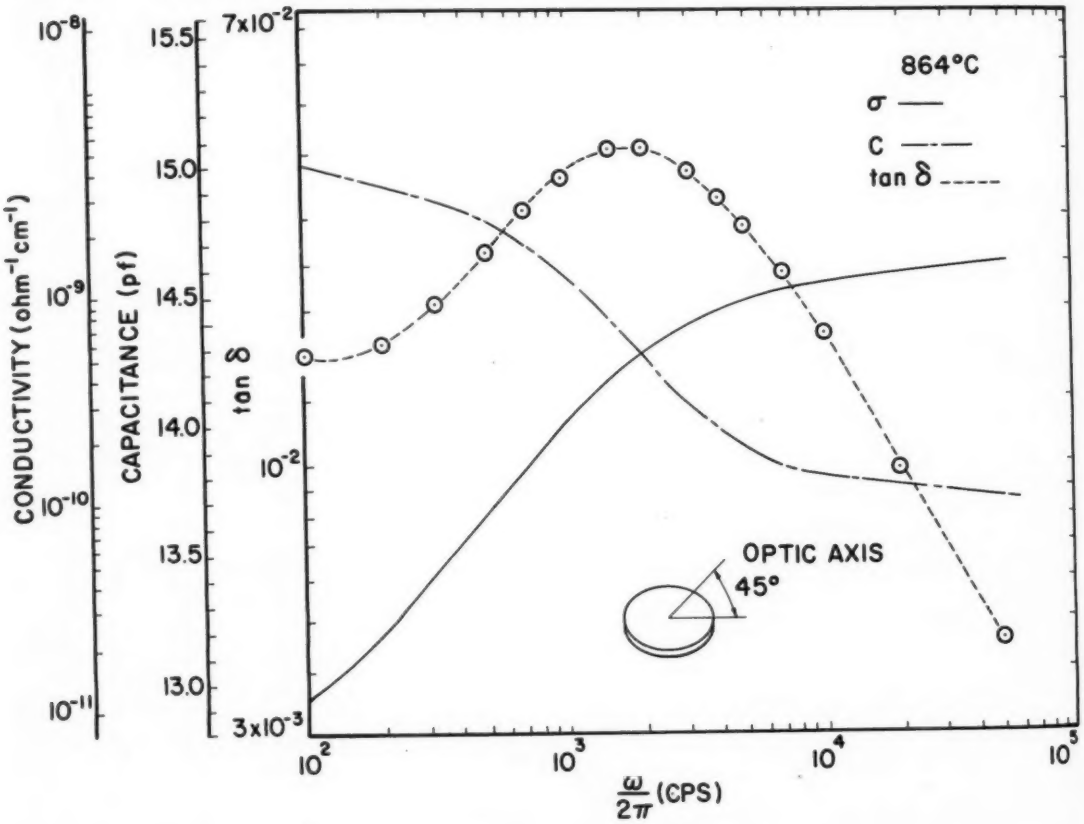

Fig. 1 Dissipation factor maximum and conductivity and capacitance dispersions in sapphire produced by a relatively high conductivity surface layer.

tion effects due to the material containing thin surface layers whose electrical properties differ from those of the bulk (after Volger (1)), the following facts are noted. The relatively small amplitude of the tan δ peak, the small capacitance dispersion and the large conductance dispersion of Fig. 1 are characteristic of a surface layer higher in conductance than the bulk (1, 2). Based on either the observed peak height or the conductance dispersion, the effective thickness of the layer is about 40μ. Figure 2 shows the results for a sample exhibiting interfacial polarization due to a surface layer lower in conductance than the bulk. (Large dispersions and large tan δ).

Further evidence that the electrical properties being observed are those of a surface layer and not of the bulk crystal is given in Figure 3. "Equilibrium" tan δ curves at 700°C are shown for three pressures. The shift of the maximum with the change in pressure occurred within seconds, and therefore could not represent equilibration of the bulk at this temperature.

In some cases, the observed activation energies changed from that characteristic of cation conduction to that for anion conduction during measurements at relatively low temperatures. Here again, a change in the composition of the surface layer, specifically the relative vacancy concentrations of the two carriers, was occurring at low temperature.

However, this extremely slow atmosphere equilibration of the alumina, which is apparently controlled by the volume interdiffusion of both ionic species, is not characteristic of all materials. Some of the titinates,

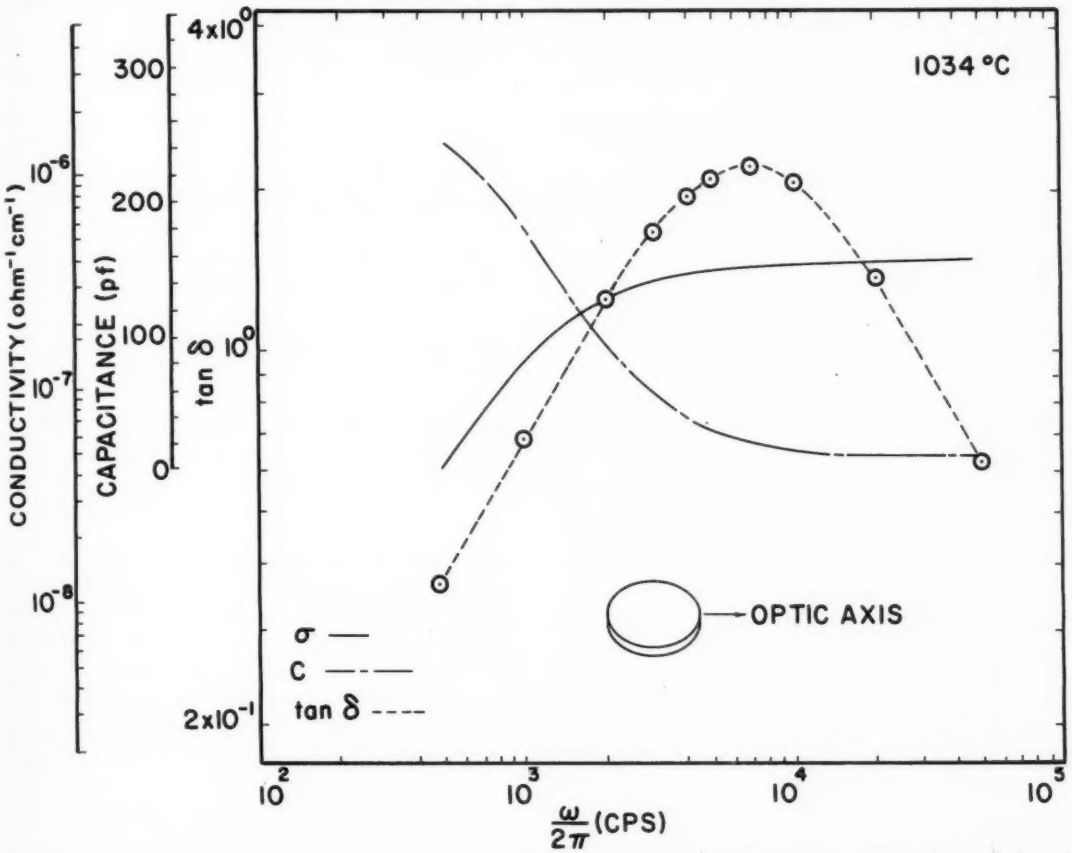

Fig. 2 Dissipation factor maximum and conductivity and capacitance dispersions in sapphire produced by a relatively low conductivity surface layer.

for example, are found to equilibrate quite rapidly (3), perhaps because of the presence of channels in the structure which provide paths for "pipe" diffusion. Therefore, it is important that the defect structure of these refractory oxides be studied as a function of the ambient atmosphere and that, whenever possible, the mechanism of equilibration be determined. In this way it may be possible to not only make optimum use of controlled defect structure to obtain desirable properties, but also to insure that these properties can be maintained in use. ★

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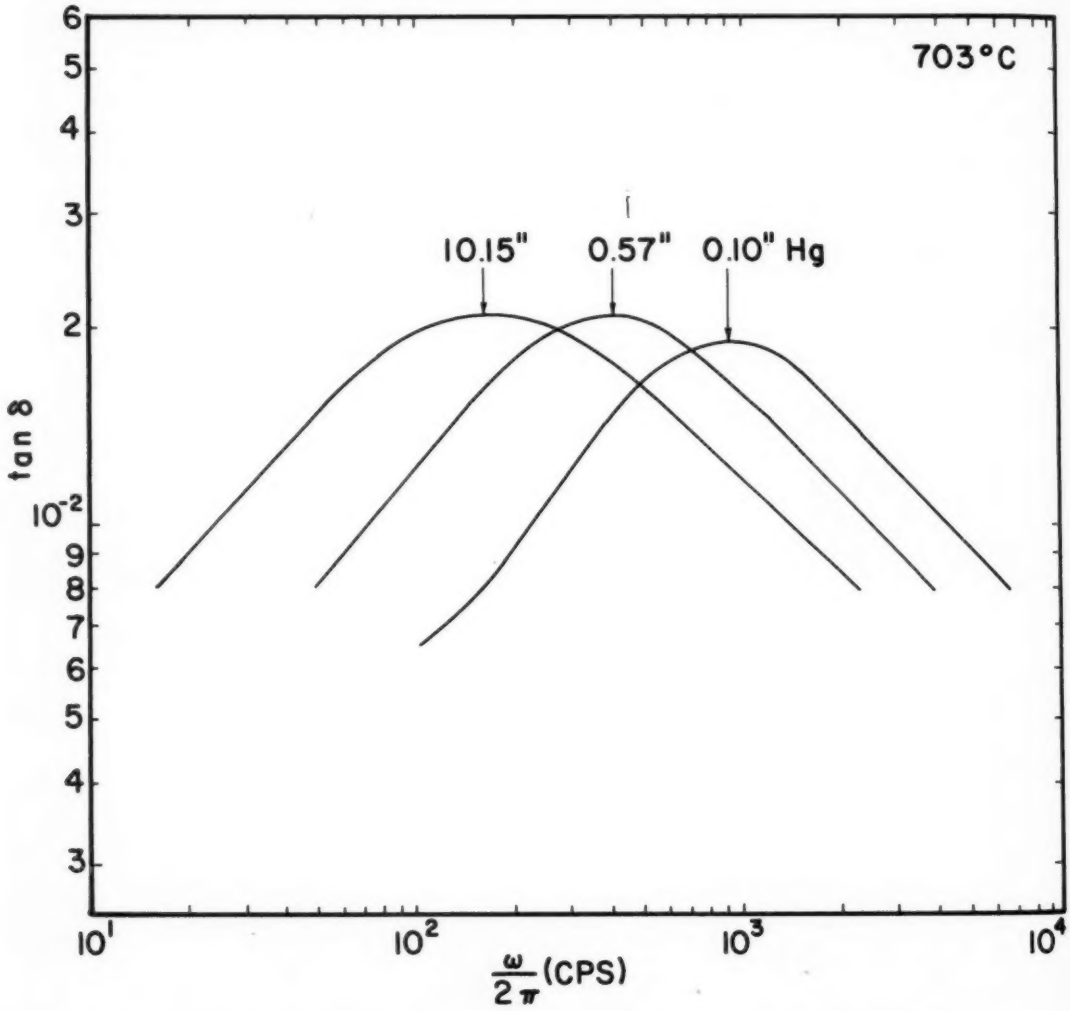

Fig. 3 Frequency shift of the dissipation factor maximum with oxygen partial pressure at constant temperature corresponding to changes in the conductivity of the surface layer on sapphire.

TETHERED ENZYMES

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Directorate of Life Sciences, AFOSR

Nature operates the most intricate and spectacularly successful chemical plants in the world. In every living organism, chemical transformations take place routinely that are beyond the capabilities of our most competent chemists using the best available techniques and equipment. Nature's principal tool in this impressive performance is the enzyme. The cell abounds in these specialized protein molecules which operate with a specificity and efficiency that is the envy of the organic chemist. Dozens of specific enzymes have now been isolated in highly purified form and have been subjected to every test the ingenuity of the scientist can devise. Many have been harnessed to the use of industry and medicine and biological research. Nevertheless, there has been a growing recognition that purified, isolated enzymes in the test tube do not mimic exactly their activities in the body. This difference may be partially explicable by the necessity for specific positioning within the architecture of the cell. Enzymes are not only highly specific in their actions, but may also require binding to certain cellular sites. Cellular membranes are obvious candidates for such requirements to control the entrance and egress of biological substances.

Prof. Ephraim Katchalski of the Weizmann Institute of Science at Rehovoth, Israel, for many years has been studying the biological effects of large polymers produced synthetically or through modification of protein molecules. He has succeeded in converting a number of water-soluble enzymes into insoluble forms. These can be readily removed from the reaction mixture and anchored to inert polymers to form stable and enzymatically active columns. Such columns may then be used repeatedly to induce specific changes in relatively large amounts of substrate. This has obvious applications in many industrial processes for special chemicals. Further, using short incubation periods, important intermediate products can be detected and isolated, which are too ephemeral to capture with traditional techniques. Another application is the rapid and complete removal of a single substance from a complex mixture. A column of bound urease, for example, could be used repeatedly to determine the urea content of blood and urine. This has been performed routinely in Katchalski's laboratory, with results identical with those obtained by other clinical methods. A number of other enzymatic assays are equally amenable to this approach.

Perhaps the most exciting promise of these water-insoluble enzymes lies in the exploration of the chemical processes at membrane interfaces. The transport of ions and organic substances across membranes is one of the most fundamental processes in biology and among the most poorly understood. Other AFOSR grantees are studying transport mechanisms from varying points of view. The possibility, however, of fixing various enzymes to the cell membrane should yield basic information in many vital physiological processes. A start has been made in this direction by Katchalski. He has succeeded in impregnating and fixing the enzyme, papain, to collodion membranes. He has prepared a diffusion cell consisting of two compartments separated by such a collodion-papain membrane. Experiments have been initiated to determine the enzymic activity of the membrane and the diffusion rate of various substrates and hydrolytic products. Katchalski plans to prepare a number of membranes with various enzymatic activities by coupling different enzymes to suitable membranes. This should then enable the design of model experiments to clarify active transport phenomena. One can confidently anticipate that new and imaginative applications will arise from these studies sponsored by AFOSR. ★

Col. Chinn was on active duty at AFOSR when he wrote this article.

on the application of electron paramagnetic resonance to radiation damage in II-VI semiconductors

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Solid State Physics Research Laboratory
ARL

The semiconductors being investigated at ARL are diamagnetic. This means that each electron within the crystal is magnetically coupled to another in such a way that there is no resultant net magnetic moment. Now it is clear that any defects in the structure, whether caused by impurities, or by displacements due to radiation damage, may be of two types. Either the defect retains the paired electron moments, in which case it is a diamagnetic defect, or it produces a local unpaired spin situation, a paramagnetic center. The paramagnetic centers are particularly important because one may investigate them by Electron Paramagnetic Resonance. The experiment may be described phenomenologically in the following way: there is more than one energy level associated with a magnetic moment when it is situated in a magnetic field. This can be seen with an ordinary magnetic compass (magnetic moment on a pivoted needle) in the Earth's field. There is a tendency for the N needle to point north (the direction of the lowest energy). With the electronic moment, there is also a tendency for most of them to be pointed the "proper" way. However, by providing microwaves of just the right wave length, corresponding to the value of the magnetic field and other fields present in the crystal, one may cause the moment to reverse itself. Since the relationship is well known for the wave length and the magnetic field in the absence of other fields, one may determine what the "extra" fields involved are, and hence, certain things about the center itself and, with good fortune, its identity. In using this technique, an immediate problem which had to be overcome was the evidence that, in II-VI semiconductors, and others, many of the centers observed by fluorescence anneal out of the samples at temperatures well below room temperature. This necessitates irradiating the samples at low temperature and making E.P.R. measurements on them before they have warmed up. A special apparatus had to be constructed to fulfill these requirements. The irradiation microwave cavity built at ARL is shown in Figure 1. Essentially, the device consists of a metal liquid-helium Dewar which has a cylindrical microwave cavity as an appendage to the helium reservoir within the vacuum jacket. Outside the Dewar, an aluminum-foil window lines up with the cavity to allow introduction of electrons or X rays. The Dewar is transported as a unit from a Van de Graaff electron accelerator to the E.P.R. spectrometer.

Preliminary work with ZnSe as grown, and ZnSe overlaid with selenium, have yielded some interesting results which were given by Locker and Kulp at the "Radiation Damage in Semiconductors' Conference" at Rayaumont, France last summer. The data show the existence of two or more paramagnetic centers in ZnSe following electron bombardment above 240 keV at temperatures below 80^{o}K. Due to a fundamental problem involved in interpretation of the data, the identity of these centers may be related to the existence of excess selenium in the lattice.

Work is presently under way to specifically identify the nature of the radiation-damage centers by the Electron-Nuclear-Double-Resonance technique, in which the identities of the atoms involved in the electron resonance may be determined. The spectrometer for these measurements is being constructed at ARL by the author. ★

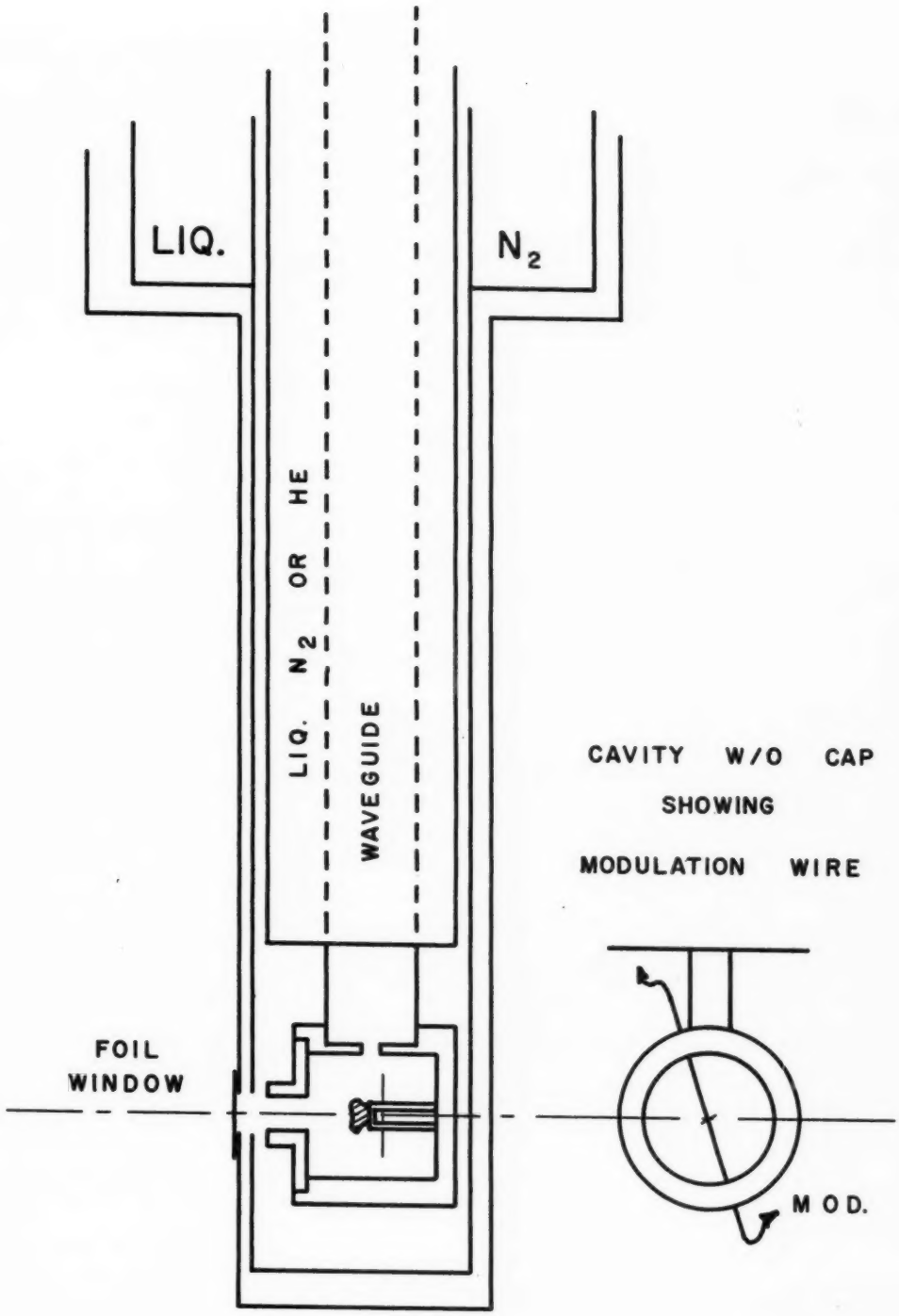
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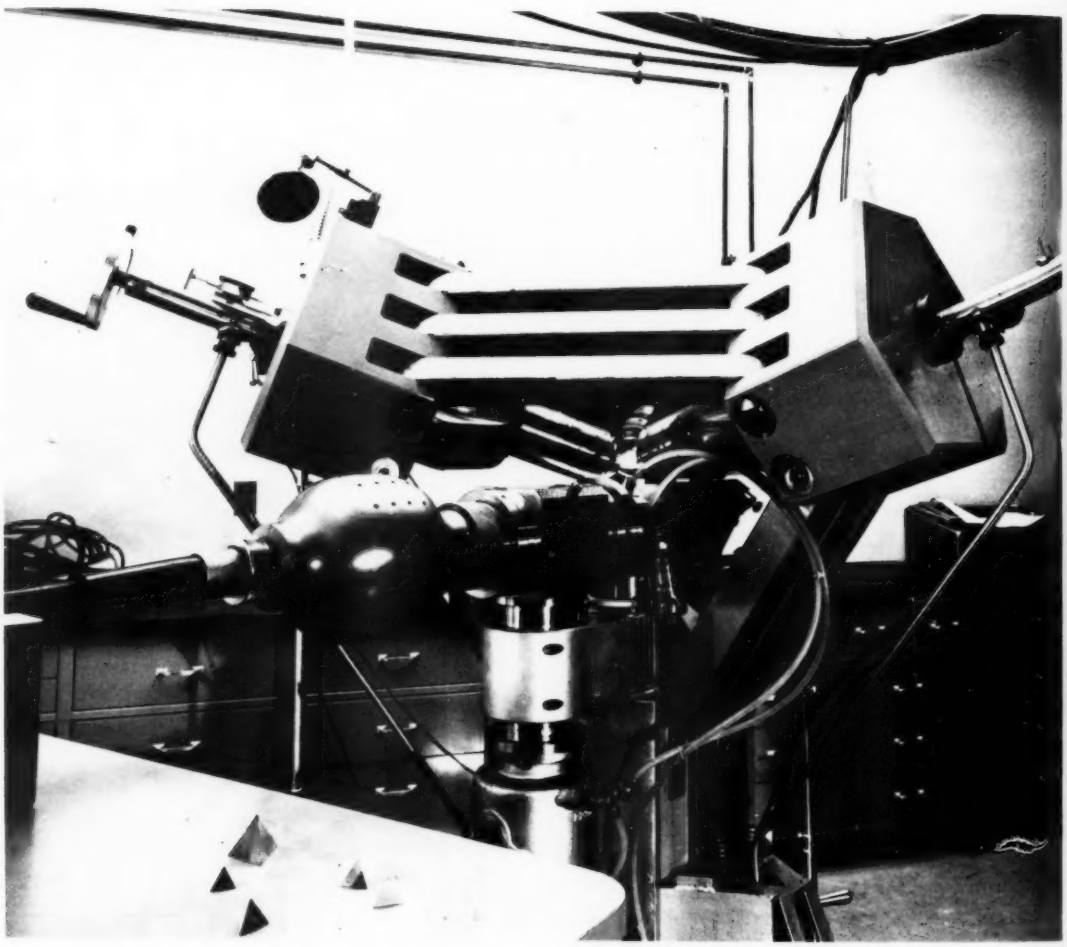
FIG. 1

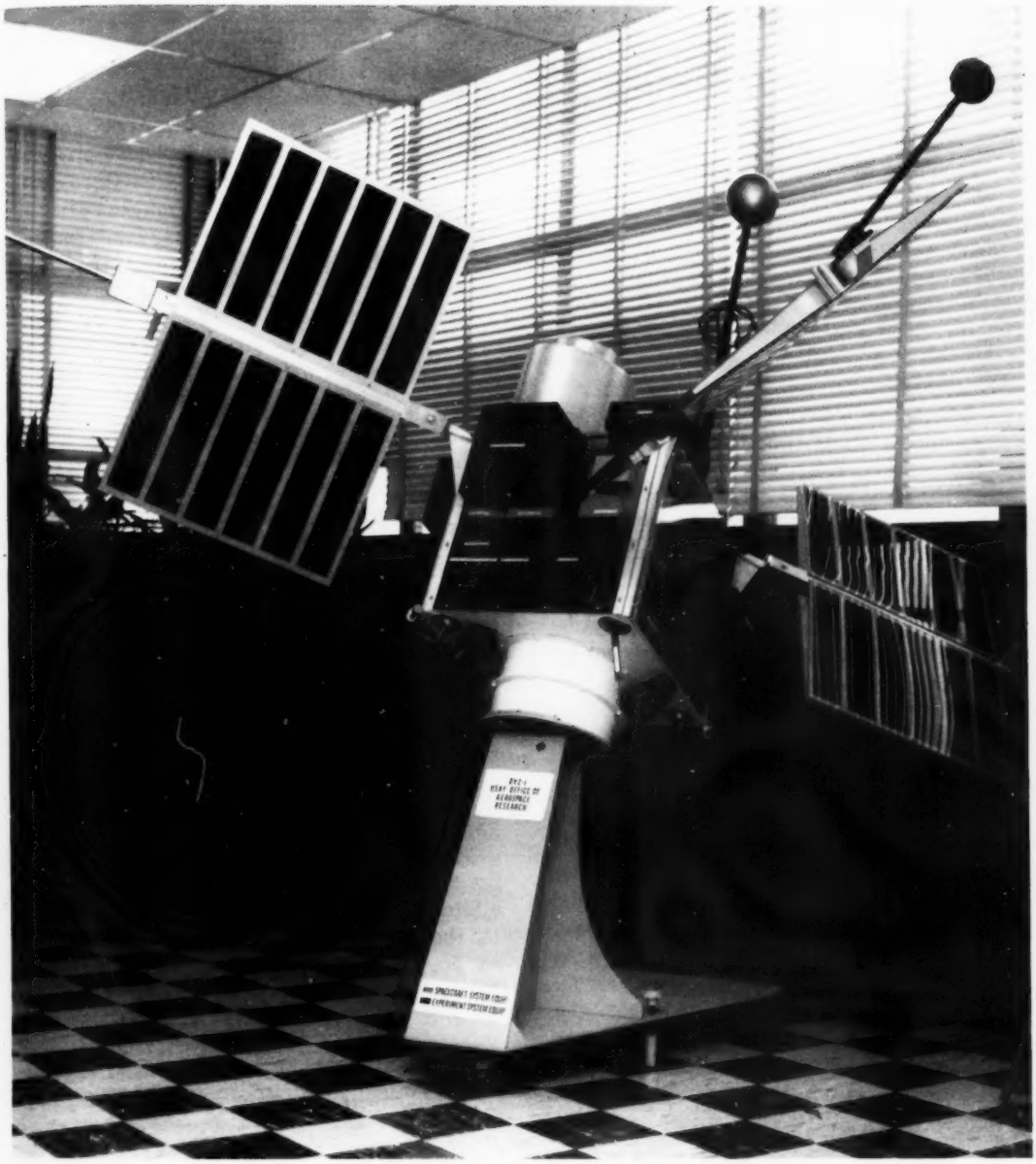
AFCRL HARDWARE



The AFCRL X-ray diamond press shown above is a high-powered X-ray diffraction apparatus which can make very-high-resolution measurements of crystals under conditions of high pressure and high temperature. This press was placed into operation for the first time last April.

In X-ray diffraction, a beam of X rays is directed into a crystalline sample and reflected from the atoms in the crystal. The reflected X rays identify the phase because they are characteristic of the crystal structure.

With this apparatus, AFCRL scientists can observe the transition of graphite to diamond while it is occurring. This transition involves a phase change in the lattice structure of the carbon materials.



Shown above is a full-scale model of the OV-2 earth satellite built by Northrop Corporation. Three of these satellites are scheduled for launching in 1965, carrying AFCRL experiments. Experiments by Ludwig Katz and Bertram Shuman of the Space Physics Laboratory, Rita Sagalyn and James Ulwick of the Upper Atmosphere Physics Laboratory, and Lewis Block of the Optical Physics Laboratory will be carried aboard the OV-2 satellites. These experiments are designed to measure magnetic-field strengths, electrons and protons, cosmic radiation and optical radiation from the earth and space. The satellites are relatively inexpensive, each costing less than $1 million, and will be launched as secondary pay loads on Titan III test flights.

nanosecond light pulses

OPTICAL PHYSICS LABORATORY, AFCRL

A powerful arc light with a flash duration of only one billionth of a second has been developed at AFCRL. Called the "Nanolite" because its flash duration is measured in nanoseconds (billionths of a second), the device can generate up to 50,000 short, brilliant pulses a second. This represents an order-of-magnitude improvement over conventional flash lamps for a number of applications, such as ultrahigh-speed photography where extremely brilliant, short-duration flashes are needed. Since the Nanolite doesn't need the complex electronic circuitry usually required for high-repetition-rate flashing, it is compact, efficient, and relatively inexpensive.

The Nanolite was developed by Dr. Heinz Fischer of AFCRL who, for the past several years, has been working to perfect it. The heart of the device is a novel capacitor, also designed by Dr. Fischer, capable of discharging its energy in a sudden burst. The resulting pulse has a sharp vertical rise to maximum, and an equally sharp decay time. This is a difficult requirement, because the magnetic fields generated by electric currents set up inductances which oppose the flow of current and thus prevent a rapid discharge of energy. Dr. Fischer's coaxial capacitor is almost inductance-free. By varying the capacitance, and thus the energy stored in the capacitor, the length of time for a discharge through the arc channel can be varied.

Flashes as short as one nanosecond have been produced. The brightest flashes have a brilliance exceeding 30 million candles per square cm, making the Nanolite the brightest nonlaser source yet developed.

Although it requires current densities in the arc channel of over 10 million amperes per square cm to achieve this brightness, the Nanolite has a nearly unlimited lifetime because the extremely short duration of its flashes prevents electrode heating and erosion. This combination of characteristics makes the Nanolite suitable for a wide range of potential applications in addition to high-speed photography. Among these applications are: 1) as a light source for flash photolysis--the study of chemical reactions produced by light; 2) for measuring the response times of photodetectors; 3) for studying recombination phenomena in the afterglow of an electric arc; and 4) its extremely short current pulse can be used to drive diode lasers for a high power output at room temperature. (This is an application to which MIT's Lincoln Laboratory has already put the Nanolite.)

In the November 1964 issue of Applied Optics, Dr. Fischer describes the use of the Nanolite as a light source for high-repetition-rate photography of fluid atomization. The Nanolite was ideally suited for this purpose because of the small size of the particles involved. Although atomized droplets travel at the relatively slow speed of about 100 feet per second, they travel a sizeable fraction of their 0.2-mm diameters in a few hundred nanoseconds. Therefore, exposure times in the 25-nanosecond range are needed to photograph them with sharp definition.

What makes the Nanolite particularly attractive for this kind of photography, in addition to the short duration of its flashes, is the fact that it flashes automatically up to 50,000 times per second when powered by a simple, compact, battery-operated D.C. source, and that its flashes are equally spaced. This self-pulsing or "free-firing" capability eliminates most of the expense of high-repetition-rate photography, which generally has reached for the complex electronic circuitry required to produce a series of short, evenly spaced current pulses to power the light source. The strip of pictures which Dr. Fischer took of fluid atomization using the Nanolite for a light source provided an impressive demonstration of its capability in this area. The pictures yielded complete and accurate information on the motions of particles in the spray. ★

COMPUTERS ARE NOT DUMB

CAPT. THOMAS K. BURGESS
Directorate of Information Sciences, AFOSR

Can computers think? Most scientists and engineers will say, "no." But there are a few who believe that, with guidance, computers can be made to think.

Part of this small but growing band of scientists decided to show the Missouri-born skeptics, and developed a computer program which learned how to solve trigonometric problems. This particular group of scientific pioneers, under the leadership of Dr. David L. Johnson, is sponsored by the Directorate of Information Sciences, Air Force Office of Scientific Research, OAR.

Dr. Johnson and Dr. Alistair Holden, Professors of Electrical Engineering at the University of Washington, Seattle, Washington, demonstrated this learning capacity by giving the computer only five basic trigonometric identities, and then asked the computer to solve first complex identities, which it failed to do. They then gave it simple identities, which it solved, and then progressively more complex ones until it was able to solve those it could not do at first. Each identity it solved correctly was stored (learned) and was used to help solve additional equations. This is much the same method by which you and I learned our Trigonometry.

What's that you scoffers say? Yes, computer programs have existed which do solve trigonometric problems; but these programs have a large library of identities to start with. Dr. Johnson's computer had only five. You still want additional proof! All right then--after several runs with increasingly more difficult identities, the computer was asked to resolve some it had already learned. The solution not only took less time the second time through, but the steps the computer used were more sophisticated and showed a great deal of subtleness.

How does the computer do this, you ask? The computer first takes the input equation and puts it into its internal standard form. This is done by removing the denominators, parenthesis and exponents by the appropriate multiplications. Then these terms are reordered by an established hierarchy and cancellable terms are removed.

The second routine then notates the form of the equation by developing a descriptor list. For example, $SIN^2 X + COS^2 X$ would have the following descriptor list: SIN, COS, SIN^2, COS^2, $SIN^2 + COS^2$. These descriptors are checked against the descriptors of the "learned identity" list. Matches and close fits are noted, and the identities of the matched descriptor sets which have the highest familiarity score are substituted in the equations. If both sides of the equations are not equal to 1, then the whole process is repeated.

When both sides of the equation are equal to 1, the computer reviews the process by which it has solved the problem, and then changes the familiarity scores of its identities on file. By this method, the identities that are most frequently used in each classification are the ones tried first. (In his trigonometry course many years ago, the author of this article did the same thing by building a private list of favorite identities.) Dr. Johnson's group does not believe that computers are geniuses, nor does it think they are imbeciles. Computers lie somewhere in between, depending on the quality of the guidance and tools with which they are provided.

Dr. Johnson's group is thinking about applying a yardstick to this program to determine how much the computer has learned and how much it can continue to learn. This may eventually lead to an I.Q. test for computers. ★

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Energy Band Calculations of CdS Using the O.P.W. Method

1st LT. T. C. COLLINS AND DR. R. N. EUWEMA
Solid State Physics Research Laboratory, ARL

Recently, investigations have been initiated to obtain the energy band structure of CdS and other II-VI compounds which have the wurtzite lattice. An energy band calculation yields many interesting features, such as: the curvature at the band edge gives the effective mass and the over-all structure of the conduction band which allows one to describe optical properties beyond the absorption edge. Results of the calculations not only help one to understand the observed data, but also lead to new areas for experimentation. The orthogonalized plane wave (O.P.W.) method introduced by Herring (1) was chosen because it lends itself easily to a self-consistent approach which is necessary if one does not have a good estimate of the actual crystal potential beforehand.

To compute the first electron charge density, $\rho^{\text{elec}}_{\text{crystal}}(\bar{r})$, wave functions were used which are solutions of the Hartree-Fock equation obtained by T. K. Kruger, W. L. McDavid, and S. J. Czyzak (2) for the free atom.

$$\rho^{\text{elec}}_{\text{crystal}}(\bar{r}) = \sum_{\nu} \rho^{\text{atom}}_{\text{cd}}(\bar{r}-\bar{R}_{\nu}) + \sum_{\mu} \rho^{\text{atom}}_{\text{s}}(\bar{r}-\bar{R}_{\mu}). \quad (1)$$

Equation (1), with the use of Poisson's equation, allowed the Fourier coefficients of the crystal Coulomb potential to be obtained. Further the $\rho^{\frac{1}{3}}$ approximation of Slater's (3) was used to calculate the exchange term:

$$V^{\text{ex.}}_{\text{crystal}}(\bar{r}) = 6\left\{\frac{3}{8\pi}\rho^{\text{elec}}_{\text{crystal}}(\bar{r})\right\}^{\frac{1}{3}} \text{ry}. \quad (2)$$

Having obtained the crystal potential, the Hamiltonian and overlap matrix elements are formed from projected plane waves. That is, the plane waves have been symmetrized by group projection operators and made orthogonal to the core by the following projection operator:

$$\hat{O} = I - \sum_{\text{CORE}} |\Phi_i\rangle\langle\Phi_i| \quad (3)$$

From the above, the energies and eigenfunctions are calculated. These, in turn, are used to form new electron charge densities. The process then continues until self-consistency is obtained.

At the present, spin-orbit coupling and relativisitic effects are being added to the program. Herman (4) has pointed out that the results of nonrelativistic energy band calculations can be extremely misleading if significant relativistic and spin-orbit corrections are ignored. Further, the effects of correlation are also being incorporated into the calculation from a standpoint presented in a paper by Bassani, Robinson, Goodman and Schrieffer (5). In this many-electron theory approach, it is shown that it is not a pure Hartree-Fock solution that would be required for a crystal, but a Hartree-Fock solution for which the exchange potential has been suitably screened to allow for correlation effects. ★

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ANNIHILATING DISLOCATIONS IN CRYSTALS

DR. J. THOMAS RATCHFORD, Directorate of Physical Sciences, AFOSR

Solid-state physicists have long been eager to improve the purity and structural perfection of crystals. How to annihilate the dislocations present in single-crystal specimens has been a problem of prime interest for more than a decade. Although various researchers have prepared single-crystal specimens in which no dislocations could be detected by various methods, it is quite difficult to reduce the dislocation content of most crystals to levels which will not interfere seriously with many experimental investigations.

With the advent of solid-state electronics, tremendous strides have been made in producing ultrapure semiconductor single crystals with a high degree of perfection. Ingenious crystal-growth methods have played a primary role in producing specimens from which exciting experiments and important devices alike have sprung forth. But the process of crystal growth has been, and remains, poorly understood. Dr. J. J. Gilman, while at Brown University, edited a valuable volume on the subject with AFOSR support. It is significant that in the title of this book, The Art and Science of Growing Crystals, (1) it is recognized that, in addition to automated ovens, computer-calculated temperature gradients and irreversible thermodynamics, the successful crystal grower needs the proper incantations learned from his earlier practice of black magic.

The Advanced Research Projects Agency (ARPA) materials-preparation program has as its objective the elucidation (preferably in quantitative terms) of certain of the more unpronounceable incantations. A significant part of this ARPA program has been technically monitored by the Solid State Sciences

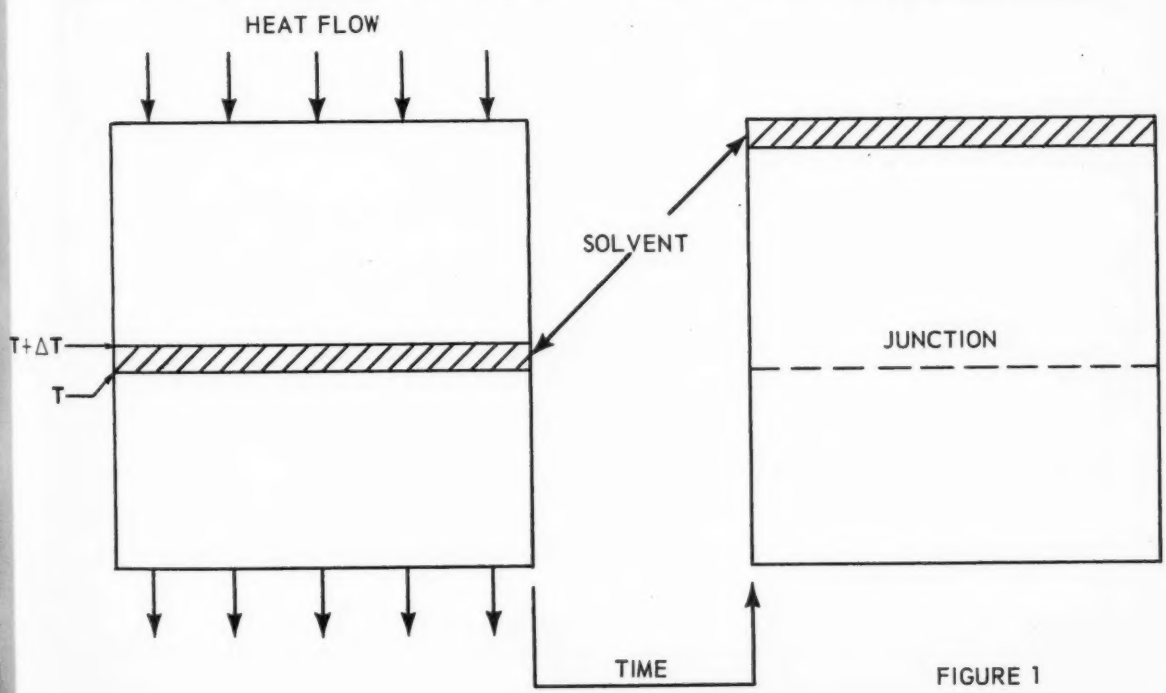

FIGURE 1

Division of AFOSR, including a project at Tyco Laboratories, Waltham, Mass., on crystal growth by the Travelling Solvent Method (TSM) (2). TSM grows crystals by moving a solvent zone, with a stationary or programmed temperature gradient maintained over this solvent zone. This method is suitable for the growth of thin perfect crystals and single-crystal rectifying junctions. A modification of this technique, in which the zone movement is induced by a moving heater element, has advantages for the growth of large crystals. This travelling heater method is especially appropriate for the growth of certain compounds and solid solutions of homogeneous composition.

TSM has been used by A. I. Mlavsky and co-workers at Tyco to grow GaAs, GaP, alpha-SiC and $SrTiO_3$. A thin zone of a solution sandwiched between two crystals moves under the driving force of the imposed temperature gradient. The boundary of the growing crystal advances due to deposition of material which dissolves from the receding interface (Figure 1). Dissolution takes place at the liquid-zone interface which is at the higher temperature. There are no mechanical driving or moving parts involved, and uniformly doped semiconductors may be produced.

Regrowth by TSM of single crystals produced by other techniques can appreciably

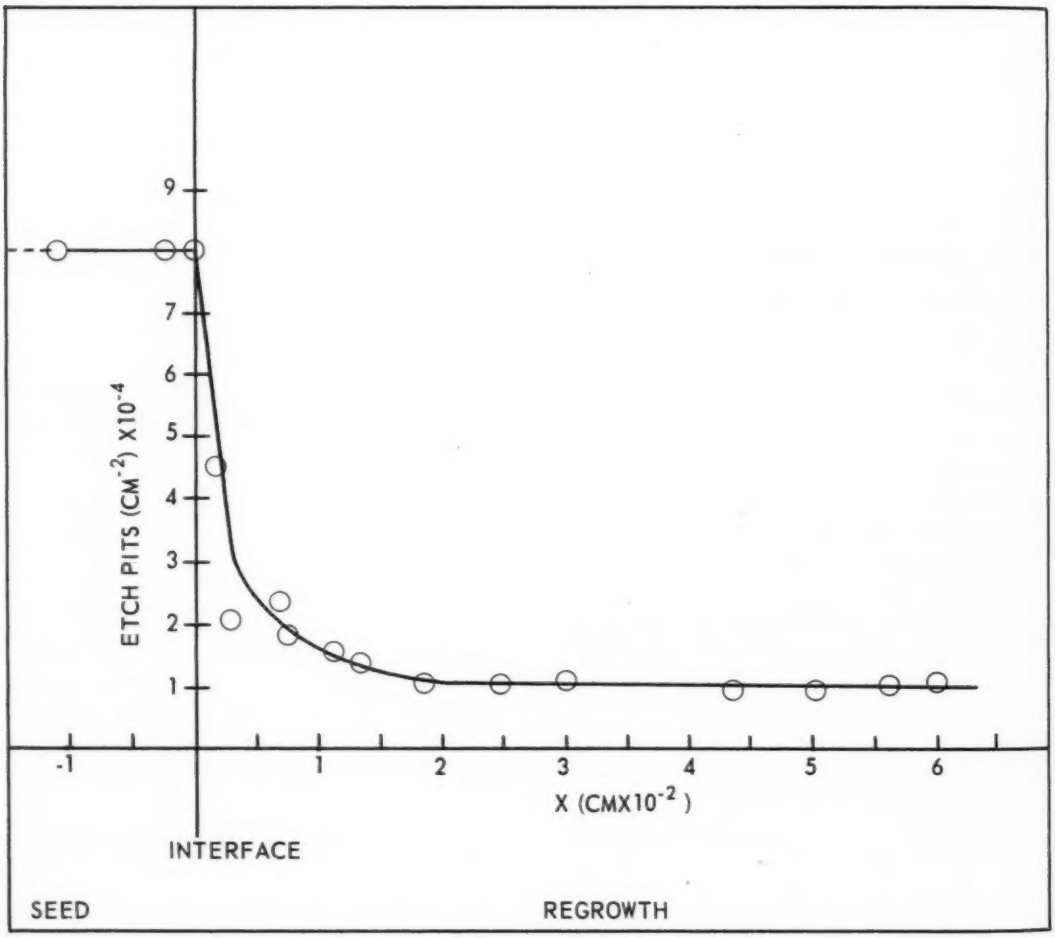

FIGURE 2

reduce dislocation content. This reduction in GaAs is shown in Figure 2, which is a plot of etch pit density as a function of distance from the initial growth interface. Figure 3 is a photomicrograph of a cross section of the interface of a $SrTiO_3$ regrown crystal, etched to show dislocation density. The etch pit studies have been verified by two different methods for detection of dislocations by X-ray diffraction microscopy: anomalous transmission (Borrmann technique) and extinction contrast (Lang technique).

Although no satisfactory detailed model has been proposed at this time, the mechanism of dislocation removal can be explained ("rationalized" may be more appropriate) in general terms. Since dislocation elimination normally involves a climb mechanism which takes place in conjunction with an initial supersaturation of vacancies, the slow growth rate, low temperature and small temperature gradient near the solid-liquid interface decreases the possibility of vacancy supersaturation. With climb unlikely, it is conjectured that the dislocations disappear because of closed loop formation, or degeneration through transformation to other types of dislocations. These dislocations then propagate normal to the temperature gradient and intersect the crystal surface.

The experiments at Tyco have shown that semiconductor crystals of high purity and low dislocation density can be grown, and that TSM is effective in reducing the dislocation content of regrown crystals. Further understanding of the process by which TSM annihilates dislocations can lead to simplified methods of producing dislocation-free crystals. ★

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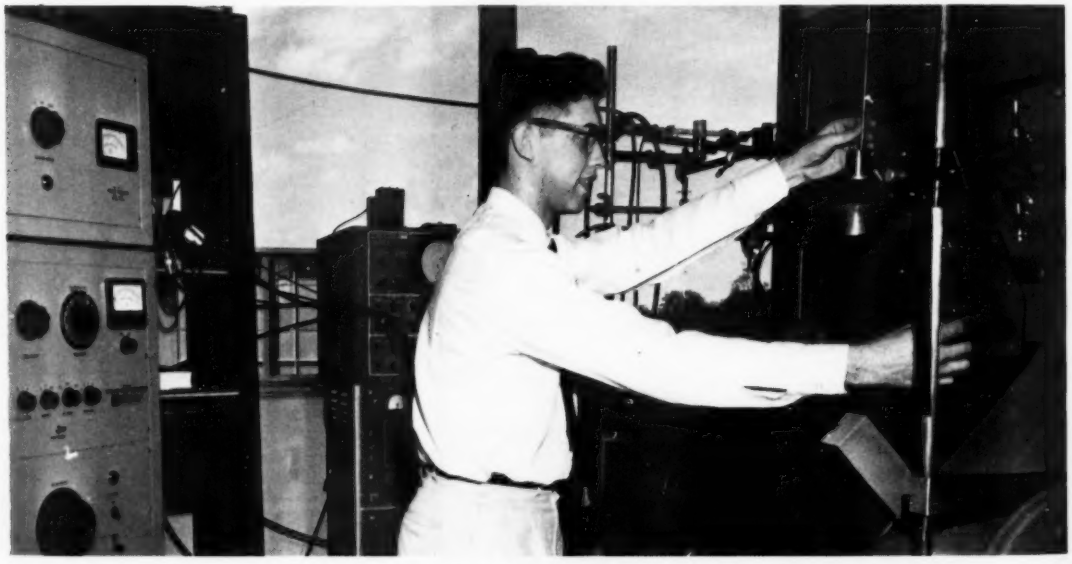
FIGURE 3

CROSS SECTION OF $SrTiO_3$ TSM SANDWICH ETCHED TO SHOW EDGE DISLOCATIONS (X680)

PROFILES

1st Lt Thomas C. Collins, an ARL scientist with the Solid State Physics Research Laboratory, is currently doing research on solid-state theory. This includes work on the exciton structure in II-VI compounds, and the energy band calculation of CdS using O.P.W., A.P.W. and S-matrix. Lt Collins has an M.S. in Physics from the University of Georgia (1960), and a Ph.D. in Physics from the University of Florida (1964). He has several publications to his credit. In this issue of the Review, he is coauthor of the article, "Energy Band Calculations of CdS Using the O.P.W. Method."



Mr. Donald R. Locker, an ARL scientist with the Solid State Physics Research Laboratory, is currently working on Electron Paramagnetic Resonance. He has perfected electron-paramagnetic-resonance equipment with superior characteristics, and is using this with a new electron-bombardment cavity to assess radiation-damage centers in ZnSe. Mr. Locker has a B.S. and an M.S. (1960), both from the University of Washington. He has several publications to his credit. He writes in this issue of the Review "On the Application of Electron Paramagnetic Resonance to Radiation Damage in II-VI Semiconductors."

Dr. Robert N. Euwema, an ARL research physicist, is with the Solid State Physics Research Laboratory. Currently, he is making crystal field theory calculations in collaboration with the ARL high-pressure group headed by Dr. D. Langer. Also, he is carrying out an investigation of the energy band structure of II-VI compounds with Dr. T. Collins. Dr. Euwema has a B.S. from The Pennsylvania State University (1954), and a Ph.D. from Princeton University (1959). He was formerly an instructor at Princeton University, and an assistant professor at Swarthmore College. He has several publications to his credit. In this issue of the Review, Dr. Euwema coauthors the article, "Energy Band Calculations of CdS Using the O.P.W. Method."

Mr. Henry C. Graham has been a research physicist at ARL for the past three years. He is with the Metallurgy and Ceramics Research Laboratory, and is currently conducting research on the measurement of the dielectric loss and capacitance of ceramic materials at 10^2, 10^3, 10^4, and 10^5 cycles per second over the temperature range from - 195°C to 1,000°C. These materials include both single-crystal and polycrystalline samples. Mr. Graham has a B.S. in Ceramic Engineering (1956), and an M.S. in Ceramic Engineering (1958), both from Alfred University. He is presently continuing his studies at Ohio State University. He has several publications to his credit. In this issue of the Review, he coauthors the article, "Composition Equilibration in Refractory Oxides."

Dr. Norman M. Tallan is a research physicist with the Metallurgy and Ceramics Research Laboratory, ARL. He has been with the Aerospace Research Laboratories since 1959. Currently, he is investigating the electrical dissipation factor and dielectric constant of nonmetallics as a function of temperature and frequency, and as a reflection of defect mechanisms. He is also investigating the electrical conductivity of nonmetallics as a function of temperature, frequency, and deviation from stoichiometry. In addition, he is looking into electrical polarization as an indication of transport numbers for electrons and ions. Dr. Tallan has a B.S. in Ceramic Technology from Rutgers University (1954), an M.S. in Ceramic Engineering from Ohio State (1955), and a Ph.D. in Ceramics from Alfred University (1959). He has a great number of publications to his credit. In this issue of the Review, he is coauthor of the article, "Composition Equilibration in Refractory Oxides."

PROFILES

Mr. Robert J. Papa is a research physicist with the Microwave Physics Laboratory, AFCRL. He has a B.S. in Physics (1955) and an M.S. in Physics (1960), both from M.I.T. Currently, he is examining those problems in re-entry physics associated with radio frequency transmission and reception through the shock-re-entry flow fields of re-entry space vehicles. He is also conducting studies of electromagnetic wave propagation through inhomogeneous and anisotropic plasmas and Boltzmann transport theory and collisional phenomena. Mr. Papa has a number of publications to his credit. He won third prize in 1963 in the Science and Engineering Award of the Aerospace Education Foundation. The article, "Electromagnetic Effects on Plasma Media," which appeared in the May 1965 Review, describes some of his work.

Dr. Kurt Toman, Chief of the Ionospheric Properties Branch, Upper Atmosphere Physics Laboratory, has been with AFCRL since 1955. He is currently studying wave interference phenomena associated with Faraday fadings of radio waves, and is conducting measurements of the Doppler effect. He is also investigating the spectral composition of truncated sinusoids. Dr. Toman studied Electrical Communications and Electronics at The Institute of Technology (Technische Hochschule) in Vienna, and received the Master's degree (Diplom Ingenieur) with distinction in 1949. He won his Ph.D. degree in 1952 at the University of Illinois in Urbana. That same year, he went on to Harvard to engage in studies of the ionosphere as a postdoctoral research fellow. Dr. Toman has a great number of publications to his credit, and is a member of several professional societies, including Pi Mu Epsilon, Sigma Xi, the Institute of Electrical and Electronics Engineers (IEEE) and others. The article, "Mechanism for Twinkling Stars," which appeared in the May 1965 Review, describes some of Dr. Toman's work.

some aspects of cosmology

DR. STUART I. FICKLER
General Physics Research Laboratory, ARL

For as long as a written record of man has existed, we know that he has concerned himself with cosmological questions. He has wondered about the beginning, and end, of the total universe of which he was aware, and has sought to understand the interrelationships of the various components that constitute the cosmos. For most of this period, these "cosmological models" were primarily based on philosophical and theological considerations, and utilized direct observation only to a limited degree.

The foundations of modern cosmology were laid by the observers of the Renaissance and post-Renaissance periods: Copernicus, Brache, and Kepler. Armed with the Aristotelian point of view that knowledge of the universe is to be obtained from direct observation, they examined the observational data of the neighborhood of the solar system and attempted to show the existence of certain regular relationships within the data. Overlapping this period came the new science of physics, established by Galileo and Newton, which produced the means by which observations of physical phenomena could be generalized and cast into the form of mathematical models which could describe and predict. Newton was strongly influenced by Kepler's work, and Newton's Universal Law of Gravitation, which can certainly be viewed as a cosmological statement, evolved from this work.

Although the beginnings of physics were strongly influenced by cosmological considerations, most of the early work in physics was concerned with phenomena that could be isolated in an earth-bound laboratory: i.e., electricity and magnetism, spectra, atomic physics, etc. Cosmology continued to grow, however, under the guidance of astronomy, which placed us as a planet that was a member of a solar system lying on the spiral arm of a galaxy. Further study revealed that our galaxy was a member of a local group which, in turn, was one of an uncountably vast number and variety of cosmological objects that filled a universe which extended beyond the limits of our sensibility.

Observational astronomy made large and significant contributions to the understanding of the universe that surrounded man; but these were largely of a gross nature, lacking in the fine details needed to bring the picture into sharp focus. It classified the celestial bodies according to size, shape, age, luminosity, etc.; it used the equations of motion of physics to describe the motions of heavenly systems. However, it could not probe the interior of these bodies and thus infer information about their structure, internal processes, and perhaps their evolution. It wasn't until the methods developed by physics with regard to spectra, plasmas, radiation, etc. were applied to astronomy that the missing information became available. Thus, once more, the sciences of astronomy and physics were joined together to form astrophysics. With this also came new impetus to formulate a theoretical model to act as a background into which the new empirical data could be imbedded. This aspect is called cosmology.

The first postulate of our theory is called the "cosmological principle" which, broadly speaking, states that the universe presents the same aspects from every point, except for local irregularities. The importance of this assumption can be appreciated if we were to suppose that the distant galaxies obeyed physical laws that were very different from those observed in the laboratory. We would then be defeated from the outset. Or suppose the universe were composed of sections that differed from each other; then our picture of the universe would vary with each different location. The cosmological principle is then invoked in order to eliminate hopeless situations such as these. This principle is essentially not new, since it is implied in

Newton's Universal Law of Gravitation. Experimentally, we do know that laboratory experiments are not affected by the position of the Earth in its orbit.

One of the earliest cosmological questions raised is known as Olber's paradox, which simply asked what appears to be a trivial question, "Why is the night sky dark?" If we stop and consider a universe filled with a multitude of stars all emitting radiation at a rate comparable with the sun, one would, in fact expect that the sky should be quite bright. Olber examined this question by starting with the following assumptions:

(a) The average density of stars and their average luminosity do not vary throughout space.

(b) The same quantities do not vary with time.

(c) There are no large systematic movements of the stars.

(d) Space is Euclidian.

(e) The known laws of physics apply.

Based on these assumptions, he carried out a calculation which revealed that, indeed, an observer on the Earth should see radiation of constant intensity and, in fact, for an infinite universe, the intensity of radiation should go to infinity. Furthermore, it showed that the major contribution of this radiation should be from the more distant regions of the universe.

Of course, this result is absurd since it contradicts the simplest observation one can make. How, then, can we resolve the paradox? Clearly, the first place to look is in a re-examination of the postulates, for the elimination or change of one of the postulates could change the outcome of the calculation. We do not wish to throw away postulates (a) and (b) since this would violate our cosmological principle and leave us without a starting point. It turns out that even if space is non-Euclidian (postulate d), but one which satisfies the cosmological principle, one would get the same results as before. Also, to throw away postulate (e) leaves us nothing to work with. Then it appears that the best place to start our re-examination is with postulate (c): no large systematic movements of the stars. In order to do this, we turn next to the Doppler shift.

It is well known in both classical physics and special relativity that, for wave phenomena, there is a frequency shift resulting from the relative motion of the source and the observer. In the case of light, if the source is receding from the observer, there is a shift to the red (lower frequency), and if the source is moving toward the observer, there will be a shift to the blue (higher frequency). It is also well known that one can obtain discrete line spectra from cosmological bodies. These result from atomic transitions, and serve to uniquely identify the elements that are undergoing transition. Suppose, then, that one obtained spectra from distant galaxies which did not correspond to any known element on Earth. This might be taken to imply that each of these objects is composed of totally different elements; but this would again violate postulate (e). Another approach would be to compare these spectra with laboratory spectra, but shift each line by the same amount and in the same direction (in particular toward the red). If, after this systematic shift, the spectral lines were to match against the laboratory spectra, we might conclude that this is a Doppler shift, and consequently the observed objects are receding from us with velocities that are related to the amount of red shift. This indeed is the conclusion that is ultimately arrived at and, as a result, we see that postulate (c) can be dropped. There are, in fact, large systematic motions of the galaxies.

A careful study of the red shift of galaxies, coupled with an independent determination of the distance to the galaxies, lead to the interesting discovery made by Hubble that the red shift is proportional to the distance to the galaxy. With our previous conclusion that the red shift is due to the Doppler shift, and thus the result of a velocity of recession, we obtain the famous Hubble relationship

$$V = \frac{r}{T}$$

where V is the radial velocity of recession, r the distance, and T a constant of proportionality. A recent evaluation of T (Sandage, 1958) gives the value of T as 1.3×10^{10} years. One should keep in mind the fact that the

measurement of distance to very far cosmological objects is not very dependable. However, even though there might be variation, the basic picture that we have been looking for has been established.

We have now come to the most economical means of eliminating Olber's paradox. By dropping postulate (c), on the basis of the empirical data described above, we come to the explanation that cosmological bodies undergo very large proper motions of a sort such that every body is receding from every other body, and the relative velocities are proportional to the separation distance. As a result, the light received at a point from distant bodies is strongly shifted to the red. It is well known that the energy, and therefore the intensity, is proportional to the frequency. Therefore, the energy received from the more distant bodies is substantially reduced. This is the concept of an expanding universe.

Having developed the idea of an expanding universe, one can now seek cosmological models which incorporate the concept of expansion. Of the models proposed, the two best known are the "big-bang theory," and the "steady-state theory." In very simple terms, the former pictures a great primordial aggregate of matter which underwent a vast explosion. The matter then moved apart with varying initial velocities depending on the effects of the explosion, and continued to separate at constant velocity, the faster material moving farther out at a greater rate. The steady-state picture views the universe as having always been as it is now. In order to interpret the red shift here, one might postulate some force which causes an acceleration such that, as the bodies separate, their velocities increase.

Although there have historically been a number of attempts to select one model over another, these have generally been inconclusive. However, there does exist one approach that could give a clear distinction between the models. This goes back to the interpretation of the red shift in each case. If we plot the velocity against distance for the "big-bang" theory, one would expect an exactly linear relationship all the way out. On the other hand, since the "steady-state" theory calls for an acceleration, one would expect a nonlinear relationship between velocity and distance. Calculation reveals that the deviation from linearity for most models will begin to show up at velocities around 0.2 c (c = the velocity of light), and will begin to show up clearly at around 0.5 c. Thus, if we could study cosmological objects that are sufficiently far away, we might be able to restrict our cosmological model. Unfortunately, there has been a problem since, until recently, the luminosity of almost all astronomical bodies has been such that existing instruments could not see past distances corresponding to 0.2 c.

We now come to an event which may well be the great revolution of cosmology. This is the recent discovery of the so-called quasi-stellar sources. Although the discovery of these objects also has significant implications concerning gravitational theory, galactic evolution, and other questions relating to the nature of the universe, we shall restrict our discussion here to the question that has been developed above. In 1963, radio astronomers identified certain very strong radio sources (power output equal to 10^{44} ergs/sec, which is comparable to the radio power output of a giant galaxy). Next, attempts were made to correlate these radio sources with an optical source. After making exceptionally careful position measurements of the radio sources, it was found that the only notable optical sources seen in that part of the sky were weak, star-like images, which it was presumed had always been in the local galaxy. Then came the big explosion: spectra were obtained from these "stars" which did not look like anything one would expect. Attempts were made to do red-shift analysis on them. This revealed that these objects were among the most distant previously seen in the universe. This, in turn, led to a reconsideration of their luminosity which showed that their optical power output had to be 10^{46} ergs/sec, which is 100 times greater than the total energy output of a giant galaxy. The red-shift data shows their recessional velocities to range from about 0.13 c to 0.47 c.

The data on these objects is still somewhat limited, and in some cases should be ap-

proached with caution. Furthermore, there are properties that have not been discussed here, which tend to deepen the mystery of the quasistellar sources, and which have led to a great deal of new theoretical speculation on the nature and evolution of the cosmos. But one thing seems quite certain--that, as more observation is made and understood, these things promise to disclose new knowledge that has previously been unforeseen, including the possibility of answering the question raised in this article. ★

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RADAR DATA INTEGRATOR

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Because clouds are turbulent, radar echoes from them fluctuate. These fluctuations result in a rather fuzzy display which makes it difficult to determine precisely the boundaries of the cloud system. A sharper, more meaningful display would be possible if these fluctuations were averaged out before display. This is essentially the purpose of the relatively simple integrator for weather radars proposed by AFCRL.

Although techniques for integrating radar data have been around since the 1940's, they either entail complex data processors, and thus are expensive, or they employ simple resistance-capacitance schemes which compromise information content. The AFCRL integrator is relatively inexpensive and does not sacrifice accuracy and resolution.

The integrator, preliminary design of which has been completed at AFCRL, will be used specifically with the vertically pointing AN/TPQ-11 radar which has recently been placed in production by the Air Force. However, the integrator may be used with any non-scanning weather radar. It is expected that a 10-db improvement in sensitivity of the AN/TPQ-11 will be obtained using the integrator. Use of the integrator will also permit the detection of weak cloud systems, and will bring about a clearer definition of cloud boundaries.

The key element in the integrator is a magnetostrictive delay line. And the key feature of the line itself is that its length, and thus its delay time, is related by a constant factor to the pulse rate of the radar. The delay line operates as a simple feedback loop. By the time one detected radar echo completes the loop, a second echo has arrived and is combined with the first. As many as 1000 pulses are thus accumulated before they are read out.

Before the detected radar echo reaches the delay line, however, it is first range-gated and converted to digital form. The digits stored and circulated in the delay line describe the signal strength of the echo. Each digital word, corresponding to some specific range element, circulates an integral number of times before being read out. Thus, new information from the same range element is available simultaneously with the previously stored information. The new and old information are combined and put back into the delay line for recirculation; thus, only integrated information circulates in the delay line. Data from each range element are read out serially and periodically.

With only average values as an output, cloud heights are displayed more meaningfully than the rapidly fluctuating values displayed when the integrator is not used. One of the displays, a facsimile recorder, presents a continuing historical record of a cloud system showing distances between cloud bases and cloud tops, as well as intermediate density variations. This display would give the observer a continuing record of the cloud profile.

The integrator is being developed and built under contract, and is scheduled for tests in the early part of 1966. Charles K. Wilk of AFCRL is the contract monitor. The 433L Systems Project Office (SPO) of the Electronics Systems Division (AFSC) is funding the program. ★

GRAVITATIONAL RADIATION

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The distinguishing feature of radiation is its capacity to transport physical quantities, such as energy and angular momentum, across empty regions of space without any net movement of matter. Sound waves, water waves, and vibrational waves on a string are mechanical analogues of radiative transport, but do not constitute bona fide radiation because they depend upon a material medium for their propagation. At present, electromagnetic waves are the only large-scale radiation fields which have been observed. Electromagnetic radiation ranging over the gamut of frequencies from radio waves to γ-rays propagates not only through the earth's atmosphere, but also across the vast empty regions of the universe. The energy may be visualized as being carried by photons, massless particles traveling with the velocity of light, which represent the basic quanta of the electromagnetic field.

This question arises--are there other massless particles in nature which manifest the properties of radiation? In the framework of elementary-particle physics, the mass and intrinsic angular momentum (or spin) of a particle are the two most fundamental labels which identify one particle from another. For instance, the photon is characterized by mass 0, spin 1. The neutrino, labelled by spin 1/2, is the only other mass 0 particle which has been observed. The neutrino belongs to the class of 1/2 integral spin particles called fermions. They therefore obey the Pauli exclusion principle, first discovered in the study of the electron, which limits the number of fermions which can be squeezed into a definite region of space. Because of this, neutrinos, unlike photons, cannot be massed together to form radiation fields of macroscopic density.

Radiation of macroscopic amplitude must be composed of massless particles possessing integral spin. Such particles are not fettered by the Pauli principle. The possibility of mass 0, spin 0 is first to be considered. Although particles with spin 0 and nonzero mass, the scalar mesons, have been observed, a massless scalar meson has not been detected. Were such a particle to exist, it would give rise to a radically different form of radiation field. The photon, because of its nonvanishing spin, can assume either of two independent polarization states, corresponding to the alignment of its spin either parallel or antiparallel to its propagation direction. The massless and spinless scalar meson would not have this choice of polarization direction. This discrepancy casts theoretical suspicion on whether such a particle might exist, although nature has the last say in these matters.

Next to be considered, after the spin 1 photon, is a massless particle of spin 2. At present, such a particle offers the best prospects for the discovery of a new radiation field, for the results of high-energy physics indicate that higher spin particles might be extremely short-lived. Even though they have not yet been observed, there is strong theoretical support for the existence of spin 2 massless particles. The support comes from the theory of general relativity which describes the nature of gravity. The structure of the gravitational field is such that it corresponds, according to the elementary-particle physicist's classification, to a field composed of massless spin 2 particles, which have been named gravitons.

Gravitation, of course, was probably the first force discovered by man. But, paradoxically, the detection of gravitons has not been accomplished. This corresponds to the state of affairs in the historical evolution of electrodynamics before the experiments of Hertz, when the presence of electromagnetic fields, such as the coulomb interaction between two charged pith balls, had been studied, but the presence of electromagnetic

radiation consisting of freely propagating photons had not been detected. The present situation in our study of gravitation is similar. Man has long been aware of the Newtonian gravitational interaction between two massive bodies, such as between the earth and sun, or two lead balls, which is analogous to the coulomb interaction between charged bodies, but has not yet detected the presence of gravitational radiation.

The mechanism for the production of electromagnetic radiation is the acceleration of charged bodies with the consequent shaking off, so to speak, of some of the photons bound in the coulomb field, which then propagate freely with the velocity of light. Similarly, the general theory of relativity predicts the production of gravitational radiation, consisting of gravitons propagating with the same fundamental velocity of light, as a result of the acceleration of massive bodies. Although it would be shocking to the foundations of physics were gravitational radiation not to exist, it has eluded detection due to the minuteness of Newton's constant which determines the strength of gravitational forces to be very weak in comparison to electromagnetic and nuclear forces. The best hope of detecting gravitational waves is from sources of immense amplitude, such as binary star systems.

Some progress toward the construction of an adequately sensitive receiver of gravitational waves has been achieved by J. Weber at the University of Maryland (1). Basically, Weber's apparatus consists of a massive block in which quartz strain gauges are embedded. The oscillations of incident gravitational radiation cause strains throughout the block which are then monitored by the piezoelectric current produced in the quartz gauges. Hopefully, Weber's receiver may soon be refined to the stage where detection is possible.

The theoretical understanding of the subject has been greatly enhanced recently due to the efforts of H. Bondi, R. Penrose, and R. Sachs (1), among others. Their work indicates that the graviton is a particle very much similar to the photon. It propagates with the same fundamental velocity, has two independent modes of polarization, and carries information, energy, and angular momentum away from its source. The most manifest distinction is that it interacts with mass rather than charge.

There is, however, a subtle but very important additional distinction. Einstein's general theory of relativity interprets gravitation as the basic field which determines the structure of space and time. While a complete understanding of the implications of this theory is still far off, the study of gravitational radiation has provided an accurate description of the structure of space-time in regions far from any massive sources, the regions analogous to the radiation and induction zones of electrodynamics. The methods which have been successful in analyzing the radiative structure of space-time are now being applied to gain deeper insight into the nature of space-time in the vicinity of the massive sources themselves. ★

References

(1) DeWitt, C., (Editor), Relativity Groups and Topology, Gordon and Breach, 1964 (for a comprehensive technical presentation).

SCIENTIFIC *note*

Biosatellite Nose-Cone Tests: AFCRL's balloon-launch group is assisting NASA in evaluating the aerodynamic and re-entry properties of a special satellite designed to carry biological specimens into space. The tests have involved releasing the satellite nose cone at altitudes between 88,000 and 100,000 feet over the White Sands Missile Range, and analyzing its behavior during free fall. Evaluated were the drogue ejection mechanism, deployment of parachute systems, descent rate, and vehicle oscillation and impact velocity. Capsules dropped from a balloon at extreme altitudes are subjected to aerodynamic forces almost identical with those occurring in a conventional re-entry. The first successful flight was made on 24 March 1965. A subsequent successful flight was made on 29 April. (Aerospace Instrumentation Laboratory, AFCRL)

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